

## LOW-WATER CUT-OFF SYSTEM

## CROSS-REFERENCE TO RELATED APPLICATION

This application is a continuation-in-part of pending application Serial No. 10/154,730, filed May 24, 2002, which  
5 claims priority from U.S. Provisional Patent Application Serial No. 60/293,444, filed May 24, 2001.

## BACKGROUND OF THE INVENTION

Field of the Invention.

10 The present invention relates to fluid level detection systems and, more particularly, to an advantageous low-water cut-off system that operates in any of a wide range of conditions and provides precise level detection with an extraordinarily wide variety of electrically conductive fluids.

15 Although the term low water cut-off system is herein used, it will be understood as being applicable to systems using fluids other than water which exhibit electrical conductivity that can be sensed for the present purposes. The term low water cut-off system is used in its general sense, regardless of the  
20 fluid to be sensed.

Known Art.

Low water cut-off systems have long been used in low-pressure and hot water boilers to cut off a burner for the  
25 boiler if there is a low water level (or other low fluid level) condition. Such low water cut-off systems may be used either for primary or secondary protection. A wide variety of such low water cut-off systems have been known or proposed, based typically either on float level detection or on electrical  
30 conductivity of a fluid whose level is to be measured.

Among the challenges in the design of low water cut-off systems are the following requirements:

The system should be preferably adjustable to provide preselected delay in its make or break operation. For example, fluid level in a boiler may fluctuate during operation, causing a possibility of possibly spurious, inaccurate or premature operation. A preselected delay may accordingly be preferred before the low water cut-off system closes control contacts (delay on make operation). Further, in the event of operation of the low water cut-off system, and/or a preselected delay may be preferred before the low water cut-off system opens control contacts (delay on break operation).

Moreover, the nature of the fluid (such as water in a boiler system) may be different from one installation to the next, being dependent, for example on impurities or additives in the fluid. Electrical conductivity of the fluid to be sensed by the low water cut-off system may be subject to a wide possible range of purity levels of the water disposed in the boiler tank.

Because low water cut-off systems of the type operating according to electrical conductivity of water or other liquid require the fluid to be conductive in order to sense its presence, high purity water, which exhibits very low electrical conductivity, can fool the device into a false low water condition. Previously, individual or special models had to be offered to the industry to handle these pure water applications.

Accordingly, it is preferred that a low water cut-off system using a probe be responsive to electrical conductivity and be capable of adjustment in probe sensitivity; however the prior art has not provided a satisfactory low water cut-off system with suitable probe and electronics arrangement in which the system is responsive to electrical conductivity. The low

water cut-off system can if desired, operate under microprocessor control. It is preferred to be capable of ready, convenient adjustment in probe sensitivity over a suitable range.

5 It is further preferable that a low water cut-off system be capable of use over such the wide range of purity levels mentioned above. It is also preferable that a low water cut-off system be fault tolerant no matter at what water purity it is adjusted to operate.

10 A difficulty in achieving such performance is that the designer is confronted, on the one hand, with a need for scaling, or attenuating, the input signal provided by a signal passing through water to be monitored at a current level which is dependent upon the conductance of the water; but also, on the  
15 other hand, with a need to establish a signal comparison threshold which will assure stable operation by the monitoring circuitry. The low water cut-off system should also advantageously operate in a fail-safe mode to assure that either it will operate normally or fail safely.

20 In general, there is also a continuing need in the art for a low-water cut-off system that reliably prevents false or premature cut-off operation in the event of temporary changes or surges in fluid level. There is a further need in the art for a low-water cut-off system that allows selective easily-set  
25 control of both make and break times during operation, and that avoids spurious, inaccurate or premature operation of the system.

Within the art, there also is a general failure to teach a low water cut-off system which could allow for rapid and  
30 convenient adjustment of the conductivity level of the fluid

with which the probe is used in order to account for the purity level of the water or other fluid in the boiler tank.

Finally, there is a need in the art for a low-water cut-off system that provides combinations of these features for use in a wide variety of low-pressure steam and hot water boilers, as well as the capability for being used in both manual and automatic reset modes.

Among the many patented low water cut-off system systems, none can be found that appears more pertinent or relevant than U.S. Patent No. 5,111,691 to John et al. which discloses a low water cut off conductance probe and control system having a time delay feature. The probe combines temperature and electrical conductivity sensing operations. However, the time delay feature utilized in said John et al. reference is fixed such that the system cannot be adjusted by the user without changing out the particular hardware arrangement described in the reference. The time delay feature of that patent has an R-C (resistive-capacitance) charging circuit in combination with an analog timer device that turns on and off an output relay to the boiler when charged or discharged by the charging circuit. More specifically, when the probe permits current flow through water filling the tank of the boiler the charging circuit begins to cause charging of a capacitor of a timing circuit. After a fixed period of time, the capacitor voltage reaches a level to enable an analog timer device which in turn activates the boiler through an output relay. Conversely, when the water level drops below a predetermined level, the probe no longer senses the electrical charge and the charging circuit discharges the capacitor over a fixed period of time. When the charging circuit is fully de-energized the analog timer device turns off the boiler.

In contrast to the John et al. reference, the present invention provides a low water cut-off system having an adjustable time delay feature implemented by a microprocessor, rather than being part of a fixed hardware circuit arrangement  
5 as found in the John et al. reference.

In further contrast with the John et al. reference, the low water cut-off system of the present invention allows a user to simply set the preferred time delay for the system at the microprocessor in order to adjust the time delay. The John et  
10 al. reference does not teach nor suggest such an adjustable time delay system much less one which is microprocessor-implemented and readily adjustable in time delay as well as other operational parameters.

Moreover, the John et al. reference does not teach nor  
15 suggest the provision of the new low water cut-off system according to the present invention for setting or adjusting the probe conductivity to the purity level of the water or other fluid in a boiler.

Finally, prior art low water cut-off systems for steam  
20 boilers that provide for delay on make and delay on break operations are not compatible with hot water boilers that do not utilize such make or break operations; therefore, separate systems must be used for each type of boiler. The present invention solves this problem by providing a single low water  
25 cut-off system that is compatible with both steam and hot water boiler applications.

## OBJECTS AND SUMMARY OF THE INVENTION

Among the several objects, features and advantages of the invention may be noted the provision of an improved low water cut-off system which:

5       --is responsive to electrical conductivity of water or other fluid used in a boiler or other device or system where fluid level must be sensed;

          --provides utility and precision as well as highly reliable operation both for low-pressure and hot water boilers to cut off  
10 a burner for the boiler if there is sensed a low water level (or other low fluid level) condition;

          --can be used either for primary or secondary protection;

          --has an adjustment feature that compensates for less  
15 conductive, pure water applications, and so provides a distinct advantage over prior low water cut-off systems in that the low water cut-off system of the present invention is capable of serving the industry as a single control which can cover a larger variety of water conditions;

          --can be used over a wide range of electrical conductivity  
20 values of fluid to be sensed by allowing selective adjustment for use in sensing a fluid with a known purity level, as when there are impurities or additives in the fluid;

          -- uses a highly precise probe and electronic circuitry responsive to electrical conductivity, yet is capable of  
25 adjustment precisely and easily in probe sensitivity;

          -- reliably prevents false or premature cut-off operation in the event of temporary changes or surges in fluid level; is microprocessor-based for solid state reliable and facile adjustment;

-- applicable for hot water boiler applications requiring no make or break operations, while also being applicable for steam boiler applications requiring make or break operations.

-- provides operation and different possible input supply  
5 voltages, such as preferably 120VAC or 24VAC;

-- operates with very low electrical power consumption;

-- permits different possible probe lengths;

--can be used for either indoor or outdoor use;

--can be used in hazardous locations as well as in remote  
10 locations;

--allows selective easily-set control of both delay on make (DOM) and delay on break (DOB) times in operation;

--avoids spurious, inaccurate or premature operation;

--provides for fail-safe operation to prevent undesired  
15 lock out upon power loss;

--includes features for assuring of reliable fault-free operation; and

--which operates in a fail-safe mode to assure that either it will operate normally or fail safely.

--is capable of being specified for use in either manual  
20 and automatic reset modes.

--provides for controllable scaling, or attenuating, the input signal provided by a signal passing through water to be monitored at a current level which is dependent upon the  
25 conductance of the water.

--which operates with a signal comparison threshold which assures stable operation by the monitoring circuitry of the system.

--which includes circuitry defining signal chains or  
30 networks which operate in modes differently defined in such a way that both chains must correctly sense for the presence of

water monitored by the low water cut-off system, so as to provide a further fail-safe characteristic.

In general, there is also a continuing need in the art for a low-water cut-off system that reliably prevents false or premature cut-off operation in the event of temporary changes or surges in fluid level. There is a further need in the art for a low-water cut-off system that allows selective easily-set control of both make and break times during operation, and that avoids spurious, inaccurate or premature operation of the system.

In a general sense, the low water cut-off system of the present invention is an apparatus for determining the presence of a fluid at a predetermined level within a fluid-containing enclosure in which the fluid can rise to the predetermined level. The apparatus operates according to a method comprising the introduction of a signal into the fluid-containing enclosure such that the signal is present for sensing within the fluid at the predetermined level, sensing for the presence of the signal within the fluid at the predetermined level, and providing a control function in response to whether the signal is so sensed, in order to indicate whether the fluid is present at the predetermined level.

More specifically summarized, the low water cut-off system of the present invention is a microprocessor-based control system for detecting the presence of an electrically conductive fluid in a vessel or tank, such as a boiler. It includes a probe for signaling a low water condition in the boiler or other vessel or tank. The system is provided with an adjustable time delay feature for preventing rapid shuttling of the device between on and off conditions whenever the water level is fluctuating about the probe. It also includes a water purity



feature that permits the user to change the conductance level of the probe in order to increase detection sensitivity when accounting for higher levels of water purity in the boiler in accordance with the electrical conductivity of the fluid. The system includes a housing containing electronic circuitry and the probe, which is operatively connected to the electronic circuitry and extends outwardly from a brass bushing carried by the housing. The electronic circuitry may include a microprocessor which permits the user to readily and easily adjust the time delay without having to change the hardware arrangement of the system. In operation, an electric current is applied to the device which flows through the housing and into the conductive fluid, such as water, that surrounds the housing. Whenever the fluid level is above the probe, the electric current flows through the conductive fluid and the probe. However, if fluid level falls below the probe, the probe no longer detects electric current generated by the device through the conductive fluid. An alarm signal is then transmitted to a remote site signaling the fact that a low fluid (low water) condition exists. Additionally, the system also shuts down the boiler whenever a low water condition continues to exist for a predetermined amount of time. The system permits preselected delay to set for either its or break operation.

According to a further aspect of improvement of the system as contrasted to the known art, system not only provides for controllable scaling, or attenuating, of the input signal provided by a signal passing through water to be monitored at a current level which is dependent upon the conductance of the water, but also operates with a signal comparison threshold as to assure stable operation by the monitoring circuitry of the system. Further, the system includes circuitry defining signal

chains which operate in modes differently defined in such a way that both chains must correctly sense for the presence of water monitored by the low water cut-off system, so as to provide redundancy establishing a further fail-safe characteristic.

5        Additional objects, advantages and novel features of the invention will be set forth in the description which follows or will become apparent to those skilled in the art upon examination of the drawings and detailed description which follow.

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## BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic view of a low water cut-off system including water probe according to the present invention.

5 Fig. 2 is a block diagram of circuitry of the low water cut-off system according to the present invention.

Fig. 3 is a schematic circuit diagram of a first embodiment of the low water cut-off system according to the present invention.

10 Fig. 4 is a schematic circuit diagram of a second embodiment of a low water cut-off system according to the present invention.

Corresponding reference characters indicate corresponding elements among the views of the drawings.

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## DETAILED DESCRIPTION OF PRACTICAL EMBODIMENT(S)

Referring to the drawings, one of the possible embodiments of the low water cut-off system according to the present invention is generally designated A in FIG. 1. Low water cut-off system A includes a housing 10 and a threaded fitting 12 from which extends an electrical probe 14 for testing the presence of liquid about probe 14. Fitting 12 may be threaded to a boiler, tank or other vessel (represented by dotted line as vessel 16 in FIG. 2) or other apparatus in which it is desired to sense the level of fluid W, such as water, or other liquid therein.

Probe 14, whether physically separate from (but interconnected with) circuitry 18, or as an integral part of housing 10, is installed into the tank or vessel at the predetermined level (indicated by the legend LEVEL in FIG. 2) at which fluid W is normally maintained. It will be understood by one of ordinary skill in the art that an alarm or cut-off or other appropriate corrective, warning or indicating action is taken if the fluid level drops below the level of probe 14, resulting from the operation of electronics 18 of the low water cut-off system A.

Referring to FIG. 2, the electronic circuitry 18 of low water cut-off system A injects a periodic signal into the conductive fluid W contained inside a vessel or tank (not shown) and employs probe 14 to sense the signal as indicative of the presence of fluid W about probe 14. Probe 14 then is used to effectively detect for the signal by probing for its presence in such fluid W when so permitted by the electrical conductivity of fluid W about the probe 14. Even though fluid W is electrically conductive it may be subject to variations in its normal

electrical conductivity as noted hereinabove. For example, the electrical conductivity is low in water of high purity, i.e., its resistance to electrical current is high. In operation, low water cut-off system A provides an adjustment that compensates  
5 for less conductive, pure water applications.

As is known in the art, the boiler may be conventionally fired by a burner (not shown) to be protectively controlled by low water cut-off system A. Housing 10 may be of the size shown, or may be larger or much smaller, and its circuitry  
10 either located in housing 10 or located remotely from the housing, but connected in any event to probe 14. Probe 14 is provided with an electrical conductive tip electrode portion 20 and an electrically insulating stand-off sleeve 20s, from which it will be shown that tip 20 provides electrical conductivity  
15 with fluid W.

#### General Operation.

Low water cut-off system A generates an AC signal and transmits the AC signal into fluid W contained within a tank or  
20 vessel. If the conductive fluid W covers the electrode in probe 14, the electronics in low water cut-off system A detect the presence of the AC signal. As long as fluid W covers the probe 14, the electronics energize a relay K1, which can be used to enable devices, such as boiler heating sources. When fluid W  
25 does not cover the electrode, low water cut-off system A detects the loss of the AC signal and de-energizes relay K1, which can subsequently disable devices, such as boiler heating sources, thereby preventing a dry fire or explosion.

Delay Operation.

In applications where short cycling of low water cut-off system A is undesirable, for example, when conditions are such that fluid W may only temporarily uncover probe 14 (as in the event of tank sloshing), programmable delay or delays may be enabled for low water cut-off system A. Thus low water cut-off system A may be configured to create a delay on make, DOM, and a delay on break, DOB. The DOM setting requires that low water cut-off system A detect fluid W covering probe 14 continuously for the specified delay setting. During the filling of a boiler with fluid W, this delay will prevent premature enabling of the heat source due to turbulence in fluid W. The DOB setting requires that low water cut-off system A detect a lack of fluid W continuously for the specified delay setting. In steam generation applications, the turbulence due to boiling will not cause premature disabling of the heat source if a DOB setting is enabled.

Specific Circuit Features and Operation.

Comparison of the block diagram of low water cut-off system A shown in FIG. 2 with the schematic circuit diagram of FIG. 3, illustrates both the specific features and specific operation of circuitry 18.

In FIG. 2, a block 14' schematically represents a functional connection for probe 14 and for a signal path 15 which includes a connection for providing a signal input to fluid W from a signal generator 19 associated with a power supply 100. As further shown, the intrinsic resistance of fluid W as sampled or tested by probe 14 is designated RW. Block 21 represents a conditioning circuit for probe 14. A compare circuit is shown by block 22. A water purity adjustment for the

compare circuit 22 allows selective calibration of low water cut-off system A for taking into account differences in electrical conductivity of fluid W, and is represented by block 23. A test circuit is shown as block 24 to provide a test  
5 signal for conditioning circuit 21 for self-testing by low water cut-off system A.

Supervision and control of low water cut-off system A is carried out by a microcontroller shown as block 25, to which is operatively connected to an output circuit 26 for providing a  
10 control function output, e.g., for burner cut-off, or other control signalling or functioning which users may wish to make of low water cut-off system A. In other words, output circuit 26 provides a suitable control function in response to whether the level-determining signal is sensed by probe 14 in order to  
15 indicate whether fluid W has a level at least as high as the predetermined level at which probe 14 is located. The control function may be used for alarm or cut-off purposes if the fluid level shifts relative to the predetermined level, marked with the legend LEVEL in FIG. 3.

20 A reset circuit is shown as block 28 for resetting of low water cut-off system A through operation of the microcontroller 25 in accordance with delay settings established by a delay setting circuit represented by block 27.

Referring to FIG. 3, more specific circuit features will  
25 now be disclosed and their operation explained in greater detail. The circuitry 18 associated with conditioning circuit 21 includes circuit components which make up the conditioning circuitry that receives an AC signal conducted by any fluid W, such as water, that covers probe 14. If no fluid W covers probe  
30 14, resistors R6, R11, and R15 will have no AC voltage applied to them. This allows R11 to pull the input of the comparator

U2B in block 22 to a low level. Conversely, if fluid W covers probe 14, the AC voltage conducts through fluid W and appears on the resistors R6, R11, and R15, and in turn, drives the input of the compare circuit 22. Compare circuit 22 stage squares the AC  
5 signal and sets the pulse width of its output relative to the water purity adjustment level, potentiometer RV1. If the conductivity of fluid W is low enough, such pulsed output will have a pulse width large enough to charge capacitor C3 above the reference set by resistors R19 and R25. When this occurs, final  
10 comparator stage U2A will generate a low voltage on its output to the microcontroller 25.

When fluid W covers probe 14, microcontroller 25 monitors the compare circuit 22 output for a high level which would indicate then that fluid W is no longer covering probe 14. If a  
15 delay setting 27 is enabled for a delay on break (DOB), microcontroller 25 monitors the compare circuit 22 output to be set continuously high for the time specified by the DOB setting. Upon expiration of the DOB time, microcontroller 25 then turns off transistors Q1 and Q3, which causes relay K1 to de-energize.  
20 LED D7 then illuminates when relay K1 de-energizes to visually indicate a low fluid condition.

So long as fluid W covers probe 14, microcontroller 25 monitors the compare circuit 22 output for a low level, which indicates that fluid W is covering probe 14. If a delay setting  
25 is enabled for a delay on make (DOM), microprocessor U3 monitors the compare circuit 22 output to determine if that output is continuously low for an interval of time specified by the DOM time setting. Upon expiration of the DOM time, microcontroller 25 then turns on transistors Q1 and Q3, which causes relay K1 to  
30 energize.



Compare circuit 22 contains a DIP switch S1 for setting delay on make (DOM) and/or delay on break (DOB). The user may set either or both DOM and DOB switch to an "on" position for bringing about the desired DOM or DOB delay. Microcontroller 25  
5 periodically reads these switches to determine appropriate timing operation. Preferably, microcontroller 25 may be a type PIC16C505.

In accordance with one aspect of the present invention, low water cut-off system A may be set for automatic reset or manual  
10 reset. Preferably, resistor R32 is a jumper installed to set the mode of reset to be implemented by low water cut-off system A.

If low water cut-off system A is installed for manual reset operation, then upon a low fluid condition, the user must  
15 manually press a reset switch S2 (when fluid again covers probe 14) to restore system A to normal operation. Block 28, the reset switch S2 and its associated components are only installed to provide a manual reset version of low water cut-off system A. Printed circuit board PCB may be used for both manual and  
20 automatic reset versions of low water cut-off system A.

If low water cut-off system A is installed for automatic reset, circuitry 18 is restored to normal operation immediately upon restoration of the fluid level to an extent covering probe  
14.

Block 24 contains circuits that will test the functionality of the low water cut-off system electronic circuits of low water cut-off system A. A pushbutton switch shunts the AC signal, if present, from the conditioning circuits in block 22. This  
25 simulates a low fluid condition to the comparator circuit in block 22 and consequently places low water cut-off system A into  
30 a low fluid state in which relay K1 becomes de-energized and LED

D7 is illuminated. The current due to the AC signal will pass through and illuminate the test LED D8. If the AC signal is not present, low water cut-off system A will already be in a low fluid condition, and the test LED, i.e, D8 will not illuminate.

5       Block 10 contains a power supply for low water cut-off system A. It comprises a transformer T1 and bridge circuit (diodes D1 and D3) to convert either 120VAC or 24VAC to 12VDC, which is then down-regulated to provide a 5VDC output for supplying these electronic circuits.

10       The signal generator, shown in block 29, uses the center taps from transformer T1. The signal generator 29 feeds two series zener diodes D9 and D10. Their outputs are capacitively coupled via C4 to the probe 14. The AC signal that capacitor C4 transmits through the probe 14 conducts into fluid W and back to  
15       block 21 if fluid W covers the electrode of probe 14.

      Although the embodiment description sets forth an arrangement for introducing an AC signal and transmitting such a signal into the fluid W contained within a tank or vessel for detection by probe 14, it would be apparent to those skilled in  
20       the art that the probe 14 can itself introduce the signal and the system configured to sense whether fluid W is a sink to the signal so introduced.

#### Second Embodiment

25       Referring now to Fig. 4, a second embodiment B of a low-water cut-off system circuitry 18 is now replaced by circuitry or system electronics including two networks supplied by a power supply 110 and an output circuit 126. The networks, as designated 122A and 122B, provide separate signal paths. Each  
30       such network has conditioning circuits, as explained below, with circuit elements similar to those of Fig. 3, and operational

amplifier comparators having similarity to those of Fig. 3, as network 122A has comparators U1A and U1D, while network 122B has comparators U1B and U1C.

Network 122A is provided to receive positive-going pulses picked up by probe 14' input 14, but network 122B is provided to receive negative-going pulses. In this regard, recognize that transformer T10 is used to provide an alternating current signal which injected into the water to be monitored by the low-water cut-off system.

An input for network 122A is provided across a regulator diode SS1 across the probe input, as referenced to node N1, representing probe circuit ground connection to vessel 16. Positive-going pulses sensed by probe 14 are provided through a potentiometer R1, connected as a rheostat to vary total resistance value and so to control input current levels in accordance with the purity of the water which is to be monitored by the system.

In network 122A, resistances R1 and R2 together are a voltage divider to serve as an attenuator for supplying pulses to a rectifier pair of diodes D1 and D2 for storage by a capacitor C2, across which is a bleed resistor R4 for providing the voltage level across C2 to the positive input of comparator U1A. Thus, a square wave of the input signal is provided at the output of said comparator for input to the positive signal input of a comparator U1D, whose inverting input is referenced by a zener diode D5, so that the output of U1D, as provided through a diode D17 is supplied to a capacitor C6.

When the pulse output of comparator U1D is sufficiently large resulting from flow of current through water in vessel 16 protected by the system and probe 14, the voltage at capacitor C8 of network 122A reaches a level sufficient to drive the base

of transistor Q1 for causing collector-emitter conduction of transistor Q1. Collector and emitter terminals of transistor Q1 are in a series path including collector and emitter terminals of a transistor Q2 in network 122B, and conduction of transistor Q2 is controlled according by operation of network 122B, which is now to be considered.

Network 122B, as compared to network 122A, receives negative-going pulses of the power supply voltage delivered to the fluid or water W in a vessel 16, so that network 122B sees the negative-going pulses resulting from flow of probe current. An input for network 122B is provided across a regulator diode SS2, for delivery through a fixed resistor R16, whose output is maintained between levels by a pair of zener diodes D7 and D8. The circuit components to the right of R16 are seen to be comparable to those of network 122A, and with the same general component layout and operation, such that sufficient flow of current through vessel 16 results in transistor Q2 being driven into a conductive state.

In output circuit 126, a relay K1 has its winding connected so as to be supplied with the unregulated output voltage of power supply 110, but across the lower end of the winding, at a terminal 4 thereof, is the circuit including the collector-emitter terminals of transistors Q1 and Q2. When conductive Q1 and Q2 clamp terminal 5 to the circuit ground. When either of Q1 and Q2 is not conductive, a resistor R15 provides a voltage at terminal 5 to the base of a transistor Q3 such that its conductivity controls an LED D15 to signal a "LOW WATER" condition. A terminal block TB1 coupled to terminals 1, 3 and 4 of the relay can be used for connection of external warning circuits or devices or for control purposes in the event of a low water condition or emergency.

Operation of Second Embodiment

Networks 122A and 122B are mutually cooperative, providing a functional effect of logic AND gating to ensure that if there is sufficient vessel level of water, as accommodated according to its purity by adjustment of pentiometer R1, both transistors Q1 and Q2 are normally driven to a conductive state. The series collector-emitter circuits provided by Q1 and Q2 is supplied with voltage from the power supply through a diode B16. When transistors Q1 and Q2 both are in their conductive state, relay K1 becomes energized and enabled which is representative of a normal water level in the boiler. If water is not present, i.e. a low water condition exists, Q1 and Q2 are cutoff and become non-conducting, thus de-energizing K1 which indicates a low water condition.

Referring again to the output circuit 126, should either of transistors Q1 and Q2 revert to an "off" stage, as in the event of insufficient water in vessel 16, or in the unlikely event of failure of either of networks 122A or 122B, or the failure of either of transistors Q1 and Q2, the winding of relay K1 is de-energized through diode D16 to cause relay contacts to open for signaling a low water cutoff condition or general alarm.

Specifically, if either of transistors Q1 or Q2 fails to conduct, as in the event of a low water condition (or a circuit fault) resistor R17 provides the voltage at terminal 5 of relay K1 to the base of transistor Q3 which has its emitter and collector terminals in a series circuiting including a resistor R15 provided with voltage for turning on a diode D15 to signal a "LOW WATER" condition.

Power supply 110 comprises components comparable to those used in the circuitry of Fig. 3. The components of the power

supply 110 will accordingly not be discussed except to note that signal nodes N1 and N2 are those representing connection to a vessel 16. Thus, it will be appreciated that transformer T1 does provide a AC voltage, i.e., a bipolar periodic signal, which is effectively introduced into vessel 16 to flows through the intrinsic resistance  $R_w$  of the water for being retrieved by probe 14; in this sense, the signal flow is introduced into vessel 16 and returns through probe 14.

Moreover, potentiometer R1 is adjustable to allow the Low water cut-off system to be adjusted for the precise purity level of liquid in vessel 16.

The advantage of the dual networks of Fig. 4 will now be still clearer to the reader, as both networks must be operating, and so also must the control resistors Q1 and Q2 both be driven for energizing the relay and indicating a normal water level being present in the boiler. If, for example, transistor Q1 should fail in such a way as to be always "ON" the reduction in signal flow through the fluid in vessel 16 will nevertheless be detected by network B causing a "LOW WATER" signal and a general alarm to be given.

For proper operation, potentiometer R1 is adjusted to a predetermined setting for proper operation, so that the incoming probe signal charges capacitor C2. If the conductance of the water is high enough, sufficient signal will charge C2 and exceed the comparison threshold set by D5 for the compare circuit of U1D.

If the water has low conductivity (high purity), R1 can be adjusted clockwise to decrease the amount of scaling (attenuation) to compensate for the conductivity of the water. The more pure the water, the lower its conductivity will be.

Network 122B represents a second signal chain which functions similarly to network 122A. However, it operates on opposite phases of the AC signal. Both networks must function correctly to detect the presence of water. This redundancy  
5 provides a fail-safe system.

As compared with Fig. 3, the system of Fig. 4 provides a more advantageous adjustment with its adjustable comparison threshold. The system of Fig. 3 utilizes adjustable scaling by signal attenuation.

10 Potentiometer R1 thus easily permits adjusting the attenuation. The circuit of Fig. 4 also provides a more fault tolerant design. If potentiometer R1 opens or shorts any of its terminal connections, the system will operate normally or fail safely. The system accordingly is compliant with an appropriate  
15 safety standard to which the product is listed.

Although the signal sensed by the probe in these embodiments may be 60Hz or 120Hz or some other multiple of the main power source, Low water cut-off systems of the invention may be designed so that the signal may also be transmitted by a  
20 radio frequency (RF) source of suitable frequency. The signal introduced in the vessel to be monitored may also be sinusoidal or of pulse-form characteristic. Other forms of signals, particularly those similarly of bipolar periodic character, such as pulses having an ultrasonic pulse repetition rate, alternated  
25 DC potentials or other sonic or ultrasonic or subsonic signals, may be used for probe sensing in accordance with the general principles herein disclosed.

Therefore, it is now seen that there is provided an advantageous low-water cut-off system for determining if water  
30 drops below a predetermined level within a water-containing enclosure, comprising (1) a signal generator operative to

introduce a bipolar signal into the water-containing enclosure such that the signal is present for sensing within water at the predetermined level, (2) a probe at the predetermined level capable of sensing the presence of the signal within the water  
5 if the water is at the predetermined level, and (3) a control responsive to the probe sensing for providing a control function in response to whether the signal is so sensed by the probe, in order to indicate thereby whether water has dropped below the predetermined level wherein the signal is transmitted through  
10 water in the enclosure according to the value of electrical conductivity of the water, including (a) provision for selectively adjusting the sensitivity of the probe sensing according to said value; (b) multiple signal paths for responding to respective different polarities of the bipolar  
15 signal sensed by the probe, and (c) a signalling circuit responsive only to proper operation of both signal paths, such that if one or the other of the signal paths fails to operate, a low water signalling will occur. In this way, low-water signalling operation is fail-safe.

20 The invention thus also is seen in macro perspective to provide a method of probe monitoring of liquid in a vessel by use of a probe associated with the vessel, comprising (a) introducing a bipolar periodic signal to the vessel for being picked up by the probe, (b) using a probe signal-responsive  
25 control operable in response to sensing of the signal by the probe, and where the method further involves (c) processing of the sensed signal, for purposes of signalling, in at least a pair of signal paths for responding to respective different polarities of the bipolar signal sensed by the probe, and (d)  
30 signalling, as for low-water warning, in response only to proper



operation of both of said at least a pair of signal paths,  
whereby said signalling is fail-safe.

It should be understood from the foregoing that, while  
particular embodiments of the invention have been illustrated  
5 and described, various modifications can be made thereto without  
departing from the spirit and scope of the present invention.  
Therefore, it is not intended that the invention be limited by  
the specification; instead, the scope of the present invention  
is intended to be limited only by the appended claims.

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